N Y O K

VARIATIONS IN THE ORBIT OF THE ECHO SATELLITE

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The ECHO satellite was launched by the NASA on August 12, 1960 into a circular orbit with an inclination of 47°, and with perigee and apogee altitudes of 1500 and 1700 km, respectively. ECHO is an aluminum-coated balloon with a diameter of 30 meters and a mass of 70.4 kilograms. Its area-to-mass ratio is 10 meters^2/kilogram, or 1000 times greater than typical values of the area-to-mass ratio for previously launched satellites.

The exceptionally large area-to-mass ratio of this satellite makes it a sensitive detector of such small effects as the pressure of solar radiation on the skin of the balloon. We have completed an analysis of the first ECHO tracking data, and find that its orbit does indeed show a substantial radiation pressure effect, as had been predicted.[1,2] The existence of the radiation pressure perturbation had already been proven, or at least strongly suggested, by the analysis of the VANGUARD I orbit, but in that case the effect was so small that two years of tracking observations were required to reveal its presence, and at the end of that time the magnitude of the pressure could still be determined only with a precision of 30 percent.

In the present instance the orbit variations produced by radiation pressure are 300 times larger than those occurring in VANGUARD I, and a relatively precise measurement is possible. We are in fact able to determine the pressure from the first month of ECHO data with an accuracy which we estimate to be 3 percent. An accurate measurement of the magnitude of the radiation pressure has a special interest, because the calculations of its orbital effects require physical assumptions, as for example in the nature of the reflection process at the satellite surface, whose validity can only be established by a comparison between the observed and computed orbit variations.

Musen's work[3] shows that the principal orbital effect of radiation pressure appears as a change in eccentricity. In Figure (1) we show the eccentricity variation of the ECHO satellite, as computed from Musen's theory by R. Bryant and A. J. Smith with the aid of a program prepared by them for the IBM 7090 at the Goddard Space Flight Center. Figure (2) shows the corresponding change in perigee height. According to Figure (2), radiation pressure diminishes the initial perigee altitude by 350 km over the course of 60 days, and we may expect that this decrease will shorten the lifetime of ECHO by a large factor.

The circles in Figures (1) and (2) represent the orbit data obtained from Minitrack observations collected by the Tracking and Data Systems area of the Goddard Space Flight Center, and analyzed with the aid of the VANGUARD orbit determination program adapted to the IBM 7090. The agreement of these data with the computed eccentricity variation provides support for the two physical assumptions made in estimating the magnitude of the solar radiation force: (i) specular reflection; and (ii) neglect of the effects of radiation reflected from the earth.

The rate of change of period of the ECHO orbit is 0.0024 min/day. From this value we can determine the mean value of the density of the atmosphere at the perigee altitude of 1518 km. Prior to the analysis of the ECHO orbit our information regarding densities was limited to altitudes below 700 km, the perigee height of VANGUARD I. Attempts have been made to extrapolate the density measurements about 700 km, but these extrapolations must be considered as uncertain by one or two orders of magnitude at 1500 km. The ECHO results correspond to a mean density of 1.1×10^{-18} g/cm^3 at 1518 km. Probable errors in the tracking data and orbit determination produce an uncertainty of a factor of two in this value. It is unaffected by radiation pressure which produces no secular changes in period. Electrostatic drag may also be neglected in this case because the increase which it produces in the effective radius of ECHO, while perhaps as large as one meter, is still small in comparison with the total rad us of 15 meters.

The quoted density at 1518 km is close to the predictions of a model developed by Jastrow and Kyle on the basis of rocket and satellite data obtained at lower altitudes,[4] but it must be emphasized that at 700 km the density of the atmosphere can vary with time of day and with solar activity by an order of magnitude, and at 1500 km these variations may easily amount to two orders of magnitude. Some knowledge of the time variations must be obtained before a significant comparison can be made with the extrapolations from density measurements at lower altitudes.

According to the initial data on the rate of change of period, the lifetime of ECHO would be approximately 20 years without radiation pressure. With allowance for radiation pressure the lifetime is reduced to one or two years. This lifetime estimate depends on the assumption that the balloon maintains a spherical form, and can be substantially altered by changes in shape and therefore in the area-to-mass ratio.

REFERENCES

1. P. Musen, R. Bryant, and A. Bailie; Science, 131, 3404 (1960)

2. R. W. Parkinson, H. M. Jones, and I. I. Shapiro; Science 131 3404 (1960)

3. P. Musen, "The Influence of the Solar Radiation Pressure on the Motion of an Artificial Satellite", Journal Geophys. Research, 65, 5, (1960)

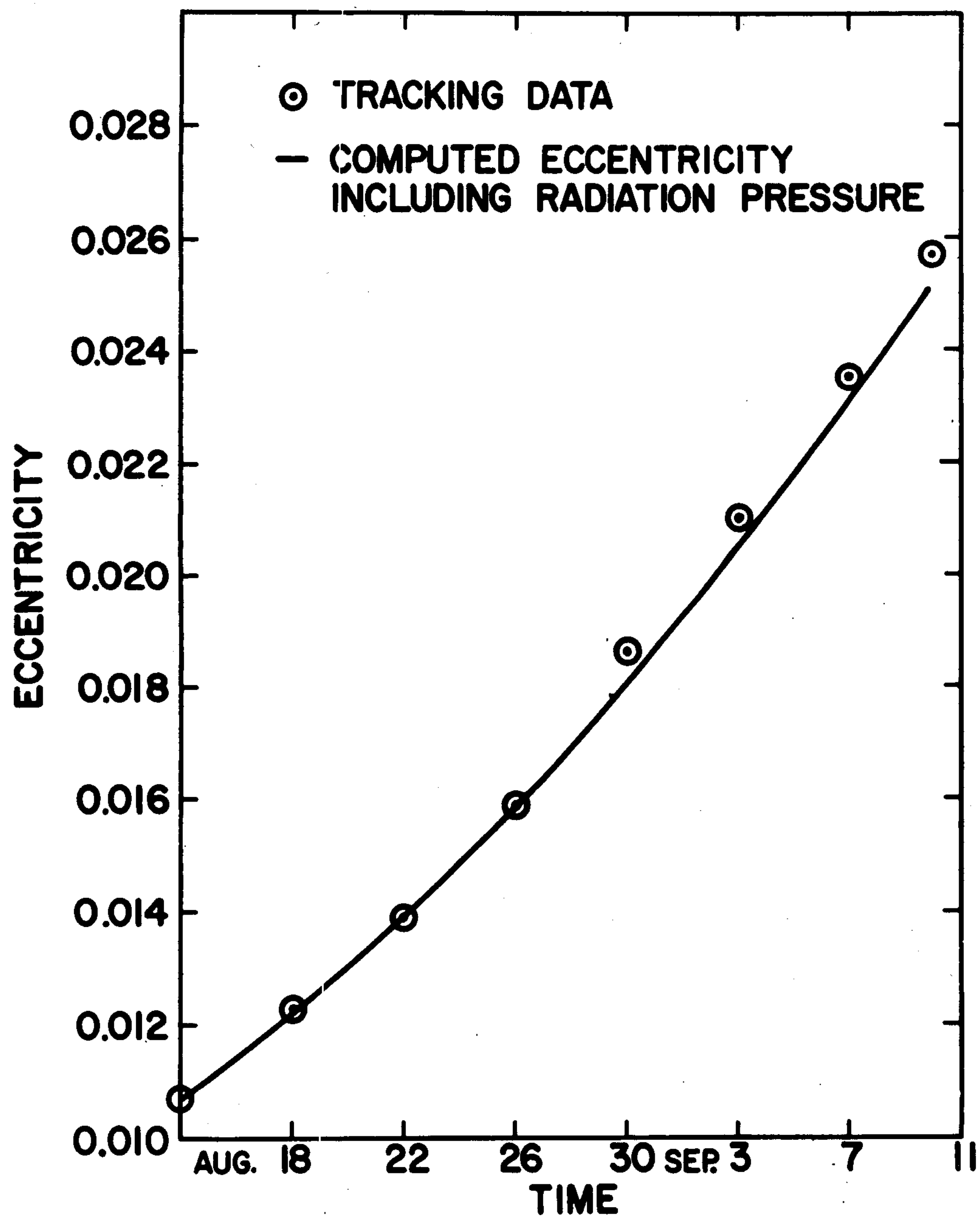
4. R. Jastrow, and H. Kyle, Astronautical Engineering Handbook, McGraw-Hill (in press)

FIGURE CAPTIONS

Figure (1) -- Theoretical variation in the eccentricity of the ECHO orbit produced by solar radiation pressure. The circles show the results of the orbit determination based on Minitrack data.

Figure (2) -- Variation in the perigee height of the ECHO orbit produced by solar radiation pressure. The circles represent perigee heights determined from Minitrack data.

ECCENTRICITY VARIATION OF ECHO SATELLITE



EFFECT OF RADIATION PRESSURE ON ECHO SATELLITE